Heavy Quark Energy Loss in Nuclear Medium

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An energetic parton propagating in a dense medium suffers a large amount of energy loss due to multiple scattering and induced gluon bremsstrahlung. In a static medium, the total energy loss of a massless parton (light quark or gluon) is found to have a quadratic dependence on the medium size due to non-Abelian Landau-Pomeranchuk-Migdal (LPM) interference effect. In an expanding medium, the total energy loss can be cast into a line integral weighted with local gluon density along the parton propagation path. Therefore, the measurement of parton energy loss can be used to study properties of the medium. Recent experimental measurements of centrality dependence of high-p_T hadron suppression agree very well with such a parton energy loss mechanism.

Because of the large mass of the heavy quark with a velocity $v \approx 1 - M^2/2E^2$, the formation time of gluon radiation, $\tau_f \sim 1/(\omega_g M^2/2E^2 + \ell_T^2/2\omega_g)$ is reduced relative to a light quark. One should then expect the LPM effect to be significantly reduced for intermediate energy heavy quarks. In addition, the heavy quark mass also suppresses gluon radiation amplitude at small angles relative to that off a light quark. Both mass effects will lead to a heavy quark energy loss different from a light quark propagating in a dense medium. This might explain why one has not observed significant heavy quark energy loss from the recent measurement of the single electron spectrum from charm production in $Au + Au$ collisions at $\sqrt{s} = 130$ GeV. In this Letter [1], we report a study on medium induced energy loss and the modified fragmentation function of a heavy quark. In particular, we will show how the mass effects reduce the total energy loss and how the dependence on medium size changes from a linear to a quadratic dependence when the energy of the heavy quark or the momentum scale is increased.

One of the mass effects on the induced gluon radiation is the "dead-cone" phenomenon that suppresses the the small angle gluon radiation. Since the size of the dead-cone $\theta_0 = M/q^-$, within which the gluon radiation is suppressed, is inversely proportional to the quark's energy, the reduction of energy loss is stronger for a slower quark. For a heavy quark with either a high energy q^- or virtuality Q^2, its radiative energy loss should approach that of a light quark. Setting $M = 0$, we recover the energy loss for light quarks as in our previous study. To illustrate the mass suppression of radiative energy loss imposed by the "dead-cone", we plot the ratio $\langle \Delta z_g^Q \rangle (x_B, Q^2) / \langle \Delta z_g^q \rangle (x_B, Q^2)$ of charm quark and light quark energy loss as functions of Q^2 in Fig. 1. Apparently, the heavy quark energy loss induced by gluon radiation is significantly suppressed as compared to a light quark when the momentum scale Q or the quark initial energy q^- is not too large as compared to the quark mass. Only in the limit $M \ll Q$, q^-, the energy loss approaches that of a light quark.

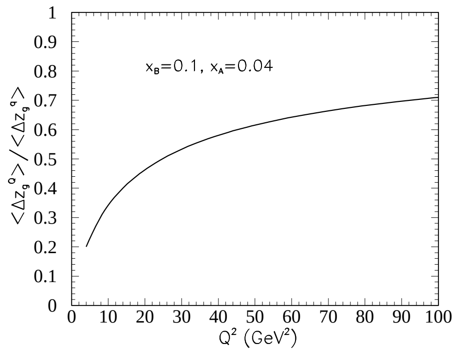

FIG. 1: The Q^2 dependence of the ratio between charm quark and light quark energy loss in a large nucleus.

In summary, we have calculated medium modification of fragmentation and energy loss of heavy quarks in DIS in the twist expansion approach. We demonstrated that heavy quark mass not only suppresses small angle gluon radiation due to the "dead-cone" effect but also reduces the gluon formation time. This leads to a reduced radiative energy loss as well as a different medium size dependence, as compared to a light quark. The result approaches that for a light quark when the quark mass is negligible as compared to the quark energy and the momentum scale Q. Similar to the case of light quark propagation, the result can be easily extended to a hot and dense medium, which will have practical consequences for heavy quark production and suppression in heavy ion collisions. As the data on direct measurement of D-meson in high-energy $A + A$ collisions become available in the near future, one should be able to use the modified fragmentation function in a parton model to study the modification of the D-meson spectra and probe medium properties similarly as has been done with high p_T light hadrons. The different pattern of energy loss for heavy quarks, such as energy and medium size dependence, will not only confirm the unique feature of non-Abelian energy loss but also give more confidence in using jet tomography to study properties of dense in heavy-ion collisions.

[1] B.-W. Zhang, E. Wang, and X.-N. Wang (2003), nucl-th/0309040.